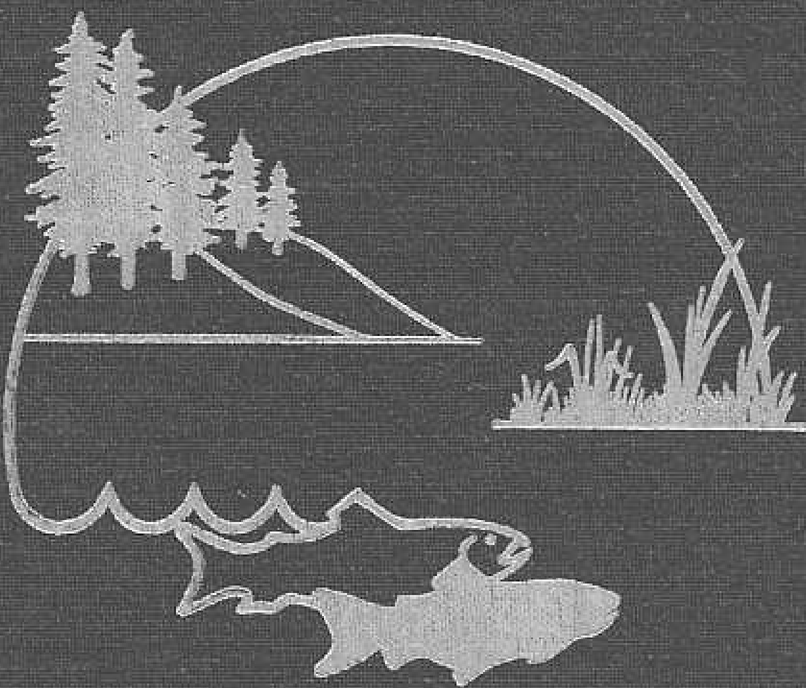
INFLUENCES OF FOREST AND RANGELAND MANAGEMENT



ON SALMONID FISHES AND THEIR HABITATS

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Chapter 8

Road Construction and Maintenance

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Forest and rangeland roads can cause serious degradation of salmonid habitats in streams. Numerous studies during the past 25 years have documented the changes that occur in streams as a result of forest and rangeland roads and related effects. Once the mechanisms of these changes are understood, it is possible to design roads that have less harmful effects on stream channels and their biota.

Only recently have steps been taken to minimize the negative effects of roads on streams. In the past, the primary considerations in road planning, construction, and maintenance have been traffic levels and economics, and little concern was expressed for the environmental influences of roads (Gardner 1979).

It should be recognized that only rarely can roads be built that have no negative effects on streams. Roads modify natural drainage networks and accelerate erosion processes. These changes can alter physical processes in streams, leading to changes in streamflow regimes, sediment transport and storage, channel bank and bed configurations, substrate composition, and stability of slopes adjacent to streams. These changes can have important biological consequences, and they can affect all stream ecosystem components. Salmonids require stream habitats that provide food, shelter, spawning substrate, suitable water quality, and access for migration upstream and downstream during their life cycles. Roads can cause direct or indirect changes in streams that affect each of these habitat components.

Many studies have shown how roads affect the physical environment of streams, and how the physical environment of streams affects fish. This research permits the diagnosis of problems and the design of engineering solutions to reduce negative effects.

Effects of Roads on Streams

Roads can affect streams directly by accelerating erosion and sediment loadings, by altering channel morphology, and by changing the runoff characteristics of watersheds. These processes interact to cause secondary changes in channel morphology. All of these changes affect fish habitats.

Accelerated Erosion Rates

Construction of a road network can lead to greatly accelerated erosion rates in a watershed (Haupt 1959; Swanson and Dyrness 1975; Swanston and Swanson 1976; Beschta 1978; Gardner 1979; Reid and Dunne 1984). Increased sedimenta-

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tion in streams following road construction can be dramatic and long-lasting. The sediment contribution per unit area from roads is often much greater than that from all other land management activities combined, including log skidding and yarding (Gibbons and Salo 1973).

Sediment entering streams is delivered chiefly by mass soil movements and surface erosion processes (Swanston 1991, this volume). Failure of stream crossings, diversions of streams by roads, washout of road fills, and accelerated scour at culvert outlets are also important sources of sedimentation in streams within roaded watersheds.

Mass soil movement.—Where forest and rangelands occur on steep terrain, mass soil movement is often the primary mode of erosion and sediment delivery to streams from roads. Four types of mass movement common to western forest lands are described by Swanston (1991): slumps and earthflows, debris avalanches, debris flows, and debris torrents. These processes are differentiated on the basis of speed of travel and shape of the failure surface. Forest and rangeland roads can increase the incidence and severity of each type of mass movement. Several studies in the western Cascade Range in Oregon showed that mass soil movements associated with roads are 30 to more than 300 times greater than in undisturbed forests (Sidle et al. 1985) (Table 8.1).

Construction of roads can increase the frequency of slope failures from several to hundreds of times, depending on such variables as soil type, slope steepness, bedrock type and structure, and presence of subsurface water. Road location is the most important factor because it affects how much all of these variables will contribute to surface failure (H. W. Anderson 1971; Larse 1971; Swanston 1971; Swanston and Swanson 1976; Lyons and Beschta 1983). Mass soil movements triggered by roads can continue for decades after the roads are built.

The most common causes of road-related mass movements are improper placement and construction of road fills, inadequate road maintenance, insufficient culvert sizes, very steep hillslope gradient, placement or sidecast of excess materials, poor road location, removal of slope support by undercutting, and alteration of slope drainage by interception and concentration of surface and subsurface water (Wolf 1982).

Surface erosion.—Surface erosion from roadbed surfaces, drainage ditches, and cut-and-fill surfaces can severely affect streams below the right-of-way (Burns 1970; Brown and Krygier 1971; Larse 1971; Gibbons and Salo 1973; Weaver et al. 1987). In a study on the Clearwater River in Washington, Cederholm et al. (1981) found that the percentage of fine sediment in spawning gravels increased above natural levels when more than 2.5% of basin area was covered by roads. The chief variables in surface erosion are the inherent erodibility of the soil, slope steepness, surface runoff, slope length, and ground cover.

Surface erosion can be the major source of sediment delivered to streams in sensitive terrain, such as areas with soils derived from granite and from highly fractured sedimentary rocks. Surface erosion and piecemeal mass movement from landslide surfaces can prolong sediment delivery to streams after initial landslide events. Such chronic secondary erosion could be as damaging to stream biota as catastrophic or episodic sediment inputs from mass-movement events, because the particles will be finer and they will be delivered over longer time periods.

Surface erosion from road networks is usually reduced through time by natural revegetation (Beschta 1978), and it can be controlled by mulching, reseeding, and mechanical slope protection (Dyrness 1970; Megahan 1974; U.S. Environmental Protection Agency 1975; Carr 1980; Carr and Ballard 1980). Reid and Dunne (1984) found that sediment yield from roadbeds increased greatly with the amount of truck traffic. Sediment loss from road surfaces is partially a function of the surface composition and road maintenance.

Other sources.—Other erosional processes can cause accelerated erosion and sediment delivery to streams. Failure of road fills is common in steep terrain, particularly on low-standard roads where road fill is not compacted or woody material is incorporated into the fill.

Where flow restrictions such as culverts are placed in stream channels, the scouring power of streamflow is increased. This can lead to increased channel scour, streambank erosion, and undermining of the crossing structure and fill.

Failure of stream crossings can be a major source of increased sediment loading of streams. When stream crossings fail, they often do so catastrophically, causing extensive local scour and deposition and additional erosion downstream. Stream-crossing failures that divert streamflow onto nonstream areas are particularly damaging and persistent (Weaver et al. 1987).

Alterations in Channel Morphology

A stream adjusts its geometry to accommodate the water and sediment it carries. When the amount of water or sediment a stream must carry increases, channel geometry must change to accommodate the increase. When channel geometry is artificially changed, such as by a stream crossing, a stream will adjust by altering its geometry upstream or downstream of the change. The nature of the adjustment depends on the original geometry and composition of the channel, how these are changed, and the ability of the channel to reshape itself. Channel adjustments that occur, in order of smallest to largest energy requirements, are changes in channel bed form, channel bed armor, channel width, channel pattern (alignment), and longitudinal profile (Heede 1980).

Hagans et al. (1986) demonstrated that road construction and inadequate maintenance lead to substantial increases in stream-channel drainage densities and channel dimensions. Adjustments can occur quickly, but often continue over many years. The adjustments usually are detrimental to fish habitat. Therefore, road crossings that modify and restrict channel geometry least, such as bridges or low-water crossings, are likely to have the least adverse effects on fish habitat.

Channel morphology is also sensitive to indirect changes resulting from other effects that roads may have on streams. Increases in sediment loading and peak flows cause changes in channel morphology that can be detrimental to fish habitat.

Other Effects of Roads on Streams

Although sedimentation and stream-channel changes are the primary negative effects of roads on streams, roads can adversely affect streams in other ways. These include changes in rainfall–runoff relationships, hillslope drainage, potential for chemical contamination, the amount and type of organic debris in stream channels, and human access to streams and fish populations.

Roads can change the stream hydrograph and affect sediment deposition in streams. Harr et al. (1975) reported an increase in peak flows following road construction. King and Tennyson (1984) found that the hydrologic behaviors of small forested watersheds were altered when as little as 3.9% of the watershed was occupied by roads.

Hauge et al. (1979) discussed several ways that roads can affect hillslope drainage, including changes in infiltration rates, interception and diversion of subsurface flow, changes in the watershed area of small streams, changes in the time distribution of water yield to channels, and changes in the fine (micro) details of drainage. These changes combine to cause a rerouting of hillside drainage that can lead to changes in erosion and the hydrologic behavior of small streams.

Chemicals used to suppress dust, stabilize or deice road surfaces, and fertilize or control roadside vegetation can enter streams directly or can be transported by runoff water or on sediment. Little is known about the effects of these chemicals on stream biota. Furthermore, a chemical-spill hazard exists wherever roads are near streams or road drainage enters streams.

Organic debris from construction clearing and landslides caused by roads can enter and block streams. These materials can cause additional erosion and alteration of channel morphology, and can form migration barriers. However, they can also provide important cover and channel diversity for juvenile fish. Removal of large organic debris at stream crossings can eliminate important components of fish habitat.

Roads allow easier human access to streams, facilitating both legal and illegal fishing. They also give access to biologists for fish habitat and population assessment, and for habitat restoration and enhancement projects. In some cases a road can be a positive contribution to a fisheries management program for a stream, provided the road is located, designed, constructed, and maintained to protect fish and fish habitats.

Effects of Roads on Salmonid Habitats

The habitat requirements of salmonids are reviewed by Bjornn and Reiser (1991, this volume). The particular habitat requirements for each salmonid species vary with the season and life cycle of the fish. All salmonids require access to spawning areas, appropriate substrates for reproduction (including substrates that can support egg incubation, alevin development, and fry emergence), and suitable water quality. Species that rear in streams for months to years before they enter the ocean also require food organisms and shelter or cover. Physical alterations in sediment loading, channel morphology, substrate composition, riparian conditions, and other road-related changes can adversely affect all freshwater stages of these fish: migration, spawning, incubation, emergence, and rearing.

Migration

Improperly designed roads can prevent or interfere with upstream migration of both adult and juvenile salmonids in several ways. Macroinvertebrate movements can also be impaired or prevented by road-related changes to stream channels (Pearce and Watson 1983). Culverts pose the most common migration barriers associated with road networks. Hydraulic characteristics and culvert configuration can impede or prevent fish passage (discussed in detail later in this chapter). Extreme sedimentation from roads can cause streamflow to become subsurface or too shallow for upstream fish movement. Likewise, stream-crossing structures can impede gravel movement in streams, leading to bed aggradation and subsurface flows that block migration. Large landslides or debris avalanches can form temporary dams that prevent fish passage (Pearce and Watson 1983). In very cold climates, large ice buildups at culverts can create barriers to migration.

Spawning

Adult salmonids have exacting habitat requirements for spawning, including requirements for substrate sizes, water depth, and velocity (Bjornn and Reiser 1991). The abundance and quality of spawning substrate can be severely affected by sedimentation. Fine sediment can be deposited in gravel interstices, even in fast-moving streams, because of the lower water velocities within the gravels. If the amount of fine material in the gravel matrix is too great, the gravels may become so cemented or indurated that fish are unable to excavate a redd.

In low-velocity stream reaches, an excess of fine sediment can completely cover suitable spawning gravel, rendering the reach useless for spawning. Excessive sediment loading of streams can also result in channel braiding, increased width:depth ratios, increased incidence and severity of bank erosion, reduced pool volume and frequency, and increased subsurface flow. These changes can result in a reduction in quality and quantity of available spawning habitat.

Gravel extraction for road construction may directly remove suitable spawning substrate. In some cases, gravel removal creates additional spawning areas, but such gravels often are hydraulically unstable. This can attract spawners to gravels that will not stay in place long enough to successfully incubate embryos.

Incubation

Successful incubation of salmonids in stream gravels depends on intragravel water flow to provide oxygen and to remove carbon dioxide and other waste metabolites (Bams 1969). If the gravel interstices are filled with fine sediments, intragravel water flow and gas exchange are reduced and egg development is slowed or halted. Fry emergence is likewise hampered by excessive fine sediments that can trap fry in the gravel (Phillips et al. 1975).

The gravels of redds must be stable throughout the incubation period. Developing embryos can be destroyed by gravel scour resulting from peak flows. Increases in peak flows and sedimentation can increase the incidence of redd destruction by scouring.

Juvenile Rearing

Increased sediment in streams can adversely affect juvenile salmonids in several ways. Most of the food items in the diets of juveniles are macroinvertebrates living in the stream. Large amounts of fine sediment reduce or eliminate much of the suitable substrate for producing macroinvertebrates, thereby limiting the food available to juvenile fish (Cordone and Kelley 1961).

Excessive sediment delivery to streams can modify the stream channel configuration, decreasing the depth and number of pools and reducing the physical space available for rearing fish. These changes can also lead to reduced survival of juvenile fish by filling interstitial spaces in the boulder and large cobble substrates where fish reside over the winter.

Riparian vegetation provides important components of rearing habitat, including shade (which often maintains cool water temperatures), food supply, channel stability, and channel structure. Road construction near streams often removes riparian vegetation directly. Mass soil movements and channel changes resulting from roads can also eliminate or damage riparian vegetation. The essential role of large woody riparian debris in salmonid streams was reviewed by Bisson et al. (1987).

Everest et al. (1987a) reviewed the effects of fine sediment on fish habitats and fish production. They demonstrated that the effects of fine sediment on salmonids are complex and depend on many interacting factors, including species and race of fish, duration of freshwater rearing, spawning escapement within a stream system, presence of other fish species, availability of spawning and rearing habitats, stream gradient, channel morphology, sequence of flow events, basin lithology, and history of land use.

How to Prevent or Minimize Damage

The basic strategy to prevent or minimize damage from roads is to understand the physical and biotic conditions that could be affected. Then, planning should ensure that roads are designed, constructed, and maintained to reduce the risks of erosion; that the risk of eroded material entering streams is low; that disturbances to channel morphology will be reduced or eliminated; that the alteration of hillslope drainage patterns will be minimized; and that fish will be able to migrate past stream crossings.

Four general principles should be considered to control erosion resulting from roads.

- Know what the erosional processes are, how roads can affect these processes, and the appropriate measures to prevent or control changes in erosional patterns.
- Avoid building roads in areas with high erosion hazards to the greatest extent possible. Minor changes in location can often prevent major problems. This is usually the single most important consideration in preventing degradation of fish habitat.
- It is almost always less expensive and more effective to design and build roads so that erosion is prevented or minimized than to control sediment once it is mobilized. Remedial measures for major erosional events usually are much more costly than preventing the events in the first place.
- Minimize the effects of roads on streams by keeping road disturbances as far from streams as possible, and by providing buffers of undisturbed land between roads and streams.

Planning and Reconnaissance

Larse (1971) pointed out that the most important steps that can be taken to minimize the impacts of roads on streams usually occur during planning, recon-

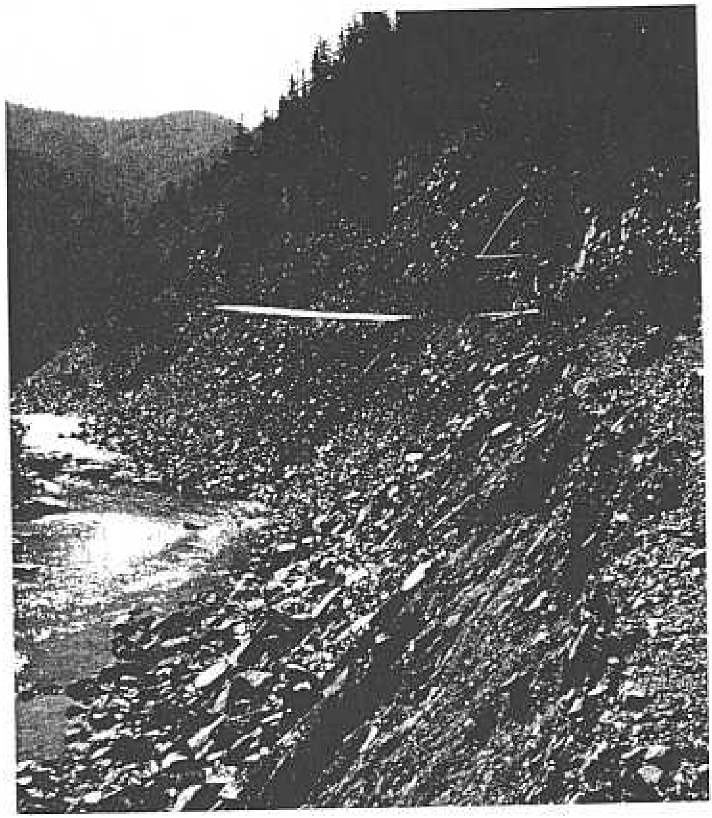

FIGURE 8.1.—Roads built near watercourses often have severe adverse effects on fish habitats. Sediments eroded from exposed and disturbed ground by rain, runoff, or streamflow move directly into stream habitats.

naissance, and route selection rather than during or after construction. Many problems can be eliminated or reduced by including on the planning team specialists such as geologists, soil scientists, hydrologists, and biologists, along with engineers. Key environmental problems and constraints are easily overlooked when routes are located and roads are designed by one person.

The following guidelines will help reduce adverse effects of roads on streams.

• Conduct long-range transportation planning for large areas to ensure that roads will serve future needs. This will result in less total road distance, roads built to appropriate standards, reduced costs of development, and fewer effects on streams.

• Use adaptable road standards to avoid sensitive areas. The prevailing planning philosophy should be to *fit the road to the landscape*. Rigid design standards, especially when limits on grade are inflexible, can severely restrict options for location, and often result in roads that pass through areas with high erosion hazards. Short grades of 14–22% can be practical for low-volume roads, and they can make it possible to avoid landslides or other sensitive areas.

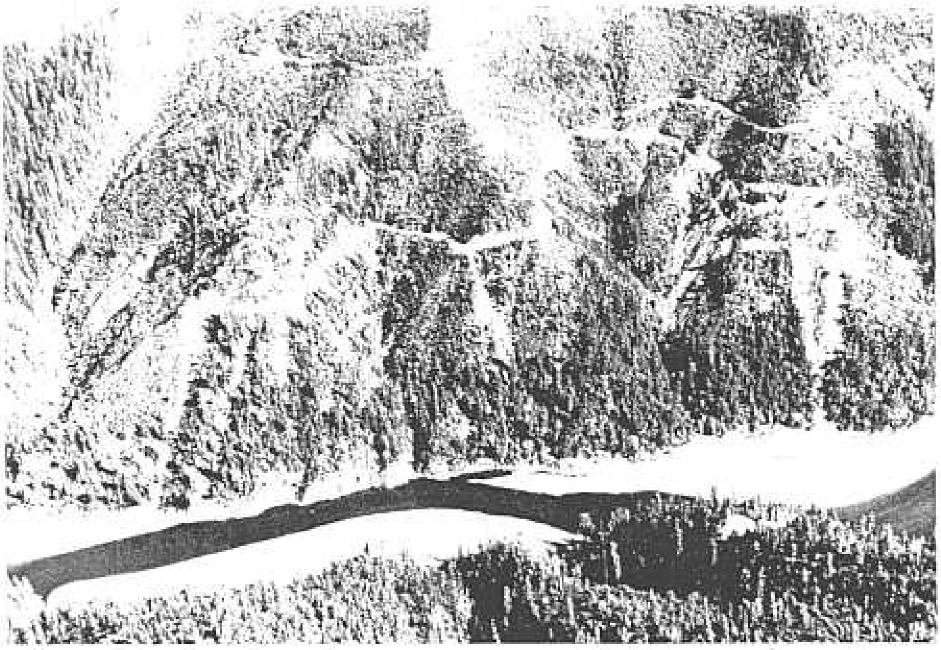

FIGURE 8.2.—Steep slopes close to waterways are high-risk locations for roads because they usually are the most erosion-prone areas in a watershed. Sediments eroded here are readily delivered to fish habitats.

• Avoid midslope locations in favor of higher, flatter areas. Ridgetop roads usually have the least effect on streams.

• Locate ridgetop roads to avoid headwalls at the source of tributary drainages. Headwall areas also are very prone to landslides (Weaver et al. 1987).

• Do not locate roads within the inner valley gorge (the oversteepened slopes adjacent to streams). These areas have the highest incidence of landsliding of any portion of an upland watershed (Wolfe 1982) (Figures 8.1, 8.2).

• Avoid slopes that show signs of excessive wetness, such as springs or water-loving vegetation.

• Avoid slopes where sidecast material could enter streams, or plan to end-haul excess material.

• Avoid slopes where large cuts and fills would be required.

• Locate roads to minimize roadway drainage area and to avoid modifying the natural drainage areas of small streams.

• Locate valley-bottom roads to provide a buffer strip of natural vegetation between the road and stream.

• Locate roads to take advantage of natural log-landing areas, such as flatter, higher, drier, and more stable terrain with good access to the timber to be removed. Good landing locations can also reduce the amount of necessary roading.

• Minimize the number of stream crossings consistent with the above considerations.

FIGURE 8.3.—A low-impact road fitted to the landscape with a narrow roadbed, narrow clearing limits, small cuts and fills, and outslope drainage. There is no inboard ditch to concentrate the erosive power of running water.

- Locate stream crossings to minimize channel changes and the amount of excavation or fill needed at the crossing.

Design

The following guidelines for road design will help minimize adverse effects on salmonid habitats.

- Use the minimum design standards practical with respect to road width, radius, and gradient (Figure 8.3).
- Minimize excavation with a balanced earthwork design wherever possible. Bench or terrace and drain natural slopes to provide a sound foundation for embankments.
- Design cut slopes to be as steep as practical. Some sloughing and bank failure is usually an acceptable trade-off for the reduced initial excavation required.
- Determine the type and extent of fish habitat before selecting criteria for drainage structure design. Bridges and arch culverts are preferred for streams with migratory fish. Where culverts are used, the gradient should be less than 1%, the culvert should be placed at or below the original streambed elevation, and

FIGURE 8.4.—Stream crossings pose the greatest risk to fish habitats of any road feature. When culverts are plugged by debris or overtopped by high flows, road damage, channel realignment, and severe sedimentation often result. The capacity of the culvert shown here was exceeded during a heavy storm, and a large slug of sediment was rapidly delivered to fish habitats downstream. Water was not diverted down the road, however. Roads should be constructed so they will not divert streams; where existing roads have the potential to do so, creation of a simple dip or "failure point" will prevent the catastrophic effects that can result from a diversion.

water depth and velocity at both low and high flows should be integrated into the design (discussed in detail later in this chapter).

• Control scouring at culvert outlets with energy dissipators such as heavy rock riprap, weirs, or gabions, consistent with fish passage considerations.

• Design drainage structures to accommodate peak streamflow based on at least a 50-year-interval flood (100-year flood for large permanent bridges and major culverts), and give consideration to the possibility that bed load and debris will restrict the flow capacity of the structure. The risk of failure can be calculated by

$$F=1-(1-1/t)^n;$$

F is the chance of failure during the design life, t is the flood recurrence interval, and n is the design life of the road or structure. For example, a culvert sized for a 50-year flood has a 33% chance of failure during a 20-year design life. Campbell and Sidle (1984) described methods for predicting peak flows and sizing culverts for small watersheds. Keep in mind that, whatever the design life, any crossing structure has a virtually 100% chance of failing over its installation life if it is not removed after the road is abandoned.

• At stream crossings, avoid channel-width changes and protect embankments with riprap, masonry headwalls, or other retaining structures. Align culverts with the natural course and gradient of the stream. Debris that floats during high

FIGURE 8.5.—If road drainage becomes concentrated, it must be discharged into places that can handle the flow without accelerated erosion. When the natural drainage of small streams is changed and concentrated flow is discharged into nondrainage areas, severe gullying and landslides can result.

streamflow can plug or restrict flow at culverts, causing severe changes in road embankments, streambanks, or channels (Figure 8.4). Trash racks can reduce culvert plugging, but can easily become barriers to fish passage. Avoid the need for trash racks by designing culverts to pass debris downstream.

• Wherever possible, disperse drainage rather than concentrating it, except in streams. Always strive to keep water flowing where it would naturally flow.

• Avoid the discharge of large amounts of concentrated runoff onto nondrainage areas (Figure 8.5).

• Do not change natural drainage areas by means of culvert or waterbar placement.

• Surface forest and rangeland roads wherever practical to control erosion and to maintain the surface drainage configuration under expected traffic conditions. Design road surfaces to remain stable and erosion-resistant during the wettest period of use. Control access on roads intended for dry-season use only.

• Use outslope drainage wherever feasible to disperse runoff. This results in the least potential for erosion and does not require as wide a road (no ditchline).

Generally, outslope drainage works well where sideslopes are greater than 20% and grades are less than about 12%, and where surface configuration can be maintained. Insloping with frequent cross-drainage is appropriate on roads with steeper grades. Cross-drainage on outsloped roads should be considered as a backup to outsloping, which can become ineffective under some traffic and surfacing conditions.

• Where inslope-and-ditch drainage is used, relieve the ditchline of drainage at frequent intervals onto areas that will not erode excessively or cause sediment to enter streams. Special care must be taken to avoid discharging drainage onto areas prone to gullying, slumping, or landsliding. Ditches along steep grades and in sensitive areas should be lined with rock to control ditchline erosion.

• When discharging drainage onto a long, erodible fill, use a discharge pipe or flume to convey the drainage to the bottom of the fill. Place energy dissipators at the outlet.

• Provide for vegetative or mechanical stabilization in areas where cut-and-fill erosion will cause sediment delivery to streams. Several publications describe erosion-control measures for cut-and-fill surfaces (Patric 1976; Carr 1980; Carr and Ballard 1980; Rothwell 1983; Swift 1986).

• Keep approaches to streams as close to right angles as possible to minimize streamside disturbances.

• Develop a specific plan for stream-crossing construction that addresses stream diversion, disturbance limits, equipment limitations, erosion control, and the operational time period when disturbances caused by construction can be most easily limited.

• Where necessary, use retaining walls with properly designed drainage to reduce excavation, contain bank material, and prevent stream encroachment.

• Design and construct stream crossings so that they will not divert streamflow out of the channel and down the road alignment if the culvert should fail or plug with debris (Figure 8.6) (Weaver et al. 1987).

• Field-check the designs before the plan drawings are complete to make certain that the design fits the terrain, that drainage needs have been met, that all critical slope conditions have been identified, and that appropriate solutions have been designed for all problem areas.

Construction

A challenge to the road builder is to construct the designed facility with the least possible disturbance of the right-of-way and without damage to or contamination of the adjacent landscape and streams. Poor construction practices can lead to severe erosion problems, toxic spills, and other water-quality problems. The following construction practices will help reduce adverse effects on salmonid habitats.

• Schedule construction during noncritical times for the local fish populations. Consult a fisheries biologist for this information. For example, avoid construction when eggs or alevins are in the gravels downstream, and do not restrict or block streamflow when adult fish are migrating upstream.

• Ensure that erosion-control measures are completed prior to rainy weather, even if construction is incomplete.

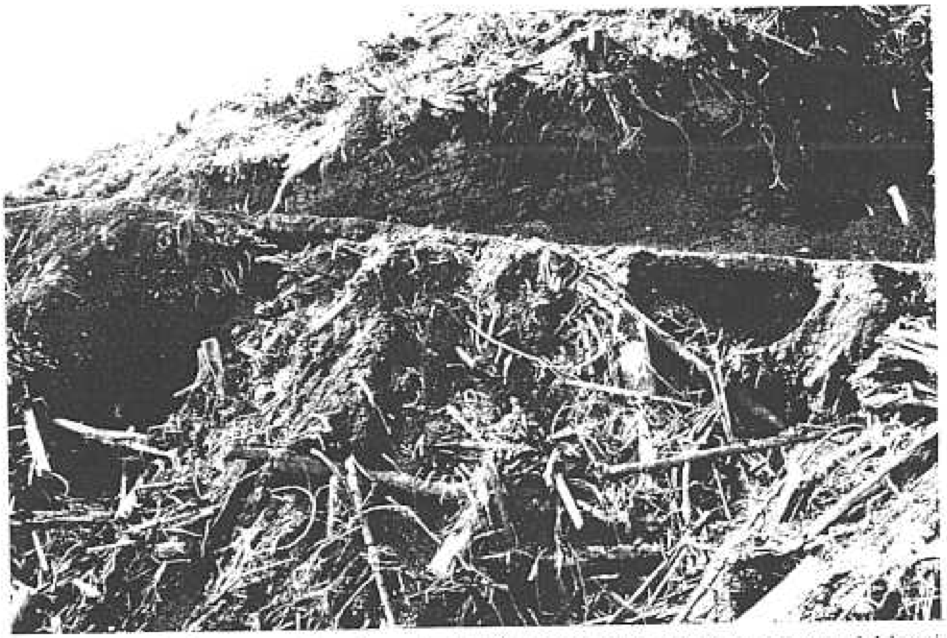

FIGURE 8.7.—Incorporation of woody debris into road fill and sidecast material inevitably leads to mass failure and surface erosion.

- Remove earth material and debris from streambanks so they cannot enter the stream later.
- Locate fuel storage areas well away from streams, and construct dikes to contain the largest possible spill. Leaks of motor oil and hydraulic fluids from heavy equipment should be monitored and controlled to prevent water contamination.
- Restrict gravel-removal operations to areas above the high-water level of the design flood. Coordinate gravel removal with a fisheries biologist. Sometimes beneficial changes can be made, but only when the fluvial system is understood and great care is taken.
- Locate and construct water withdrawal points to prevent streambank degradation and sedimentation.
- Locate road-building camps away from streams and manage wastes properly.
- Use spill-control planning and practice to keep construction toxicants out of streams.
- Do not incorporate woody or vegetative material into road fills (Figure 8.7).

Maintenance

Regular maintenance is required to keep roads in good condition and to identify and correct problems promptly. Preventive maintenance should be practiced on *all* roads, not just actively used roads. Maintenance requirements should be considered during planning and design. The higher initial costs of designing and constructing roads that weather well can be amortized by lower maintenance costs. The following practices will help reduce the adverse effects of road deterioration on salmonid habitats.